

A METHOD OF DIRECTIONAL FILTERING
FOR POST-PROCESSING COMPRESSED VIDEO

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BACKGROUND OF THE INVENTION

The present invention relates to post-processing of decompressed digital images and, more particularly, to a method of directional, selective filtering of decompressed images.

- 10 Transform coding is a common method for compressing digital images. For examples, transform coding is featured in the JPEG (ISO 10918) standard related to still images and the MPEG-2 (ISO/IEC 13818) standard related to motion video. Generally, transform coding involves subdividing an image into smaller blocks or groups of pixels, applying a “reversible transform” (such as the
- 15 Discrete Cosine Transform (DCT)) to the pixels of the blocks, quantizing the frequency coefficients produced by the transform, and coding of the results. While transform coding can achieve a high compression ratio, information in the original image is discarded in the compression-decompression process degrading the decompressed image, especially in video sequences with considerable
- 20 motion.

- Decompressed transform coded images may include visible artifacts of the compression-decompression process. A common artifact is the “blocking” effect, also known as “grid noise.” The blocking effect is the result of the process of approximating each of the frequency coefficients produced by the transform as
- 25 one of a limited number of permitted values during the quantization step. The encoder selects a quantization parameter establishing the difference between successive permitted values and assigns each frequency coefficient to the nearest permitted value. As a result of the “rounding off” during quantization, adjacent pixels may have different quantized values even though their colors were nearly
- 30 the same in the original image causing individual blocks to be visible in the

- decompressed image. This is a particular problem in areas of uniform color and along color boundaries. In addition, the decompressed image may exhibit "staircase noise," a term which is descriptive of an appearance of an edge in the image. The staircase appearance is the result of enhancement of the blocking effect for blocks lying across an edge in an image. A third artifact of interest in decompressed images is the so called "ringing artifact" that produces jagged or fuzzy lines in the vicinity of sharp edges. All of these artifacts can be annoying to viewers of the image. Accordingly, images are processed after decompression (post-processed) to reduce or eliminate some or all of these artifacts.
- 5 Several methods have been used to remove or reduce annoying artifacts in decompressed images. Some methods attempt to recover the original image from the decompressed image and knowledge of the smoothness properties of the image before compression. Generally, these methods are complex and often iterative limiting their usefulness in real time video applications.
- 10 Filtering may also be applied to the image pixels to reduce artifacts of the compression process. For example, filtering may be applied to pixel segments of rows or columns normal to the block boundaries to smooth the color or grayscale transition across the boundary, thereby reducing the blocking effect. Classification of the block's neighborhood and filtering based on the classification can be part of
- 15 the filtering process. While filtering pixel segments normal to block boundaries is useful in addressing the blocking effect, it does not necessarily address ringing artifacts. Further, edges may be filtered and some portions of diagonal edges may be filtered repeatedly, adversely impacting the sharpness of the decompressed image.
- 20 What is desired, therefore, is a computationally conservative method of post-processing a decompressed image that effectively addresses both blocking and ringing artifacts but preserves the sharpness of edges in the image.

SUMMARY OF THE INVENTION

The present invention overcomes the aforementioned drawbacks of the prior art by providing a method of post-processing a decompressed image comprising the steps of establishing a filtering axis aligned relatively parallel to an image edge in a block of image pixels and selectively filtering a plurality of pixels arrayed substantially parallel to the filtering axis. Filtering the pixels of a block in a direction substantially parallel to an image edge in the block minimizes any impact on the sharpness of the edge. Further, the method conserves computational resources by selecting pixels for filtering that exhibit a difference from their neighbors that is likely to produce a visual artifact. Pixels that are members of blocks not likely to exhibit a blocking effect are not filtered. Further, pixels at block boundaries having values sufficiently close so as not to produce a noticeable artifact and pixels representing details are not filtered. The method can also be applied separately to the images contained in individual fields of interlaced video to avoid image complications arising from the separate processing, including compression, of the fields.

The foregoing and other objectives, features and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

- FIG. 1 is a schematic drawing of pixels of an exemplary area of a decompressed image.
- 25 FIG. 2 is a flow diagram of the post-processing method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the transform coding process an N (pixel) x N (pixel) image is subdivided into nxn sub-images or blocks and the transform is applied to the individual pixels on a block by block basis. For example, in the Discrete Cosine Transform (DCT) 5 compression process utilized by in the JPEG (ISO 10918) and MPEG-2 (ISO/IEC 13818) image compression processes the image is subdivided into 8X8 blocks for coding. FIG. 1 illustrates a portion of a larger image 10 that has been subdivided into blocks, such as the block 12 that is bounded by the block boundaries 14, 16, 18, and 20. Pixels outside of the area bounded by the block 10 boundaries are pixels included in adjacent blocks. An image edge 22, formed by the boundaries of pixels of a first 24 and second 26 color divides the block 12 diagonally. It is understood that a block of pixels, as used herein, may be any plurality of pixels defining any pattern.

Decompressed images may exhibit several artifacts of the compression-15 decompression process. The most prevalent artifact of compression is the blocking effect where the blocks created for image compression are visually perceptible in the decompressed image. In the DCT transform coding compression process, the spatial domain signal for a block is converted to a block of coefficients in the frequency domain by the application of the transform. The 20 resulting frequency coefficients are quantized or approximated as one of a limited number of discrete values permitted by the encoder. Since large areas of an original image may be of relatively uniform color or grayscale, the "rounding off" process performed by the encoder may result in pixels of nearly the same original color being assigned quantized values that are visually significantly different.

25 When the image is decompressed, the color or grayscale difference of the pixels may be sufficient to be noticeable. This is a particular problem at the boundaries of adjacent blocks in areas of relatively uniform color. The severity of the blocking effect is a function of the distance between successive potential quantized values or the quantization parameter selected by the encoder. Post-processing (often by 30 filtering) may be applied to smooth the change across block boundaries to reduce

or eliminate the blocking effect or grid noise.

Filtering a segment of a horizontal row or vertical column of pixels along each boundary of each block of an image is a computationally resource intensive process. In addition, filtering a column or row of pixels extending to the center of 5 the block 12 would result in filtering of the image edge 22. Some portions of a diagonal image edge, such as edge 22, may be filtered more than once. As a result, the sharpness of edges in the decompressed image will be degraded. The present inventor realized that computational resources can be conserved by selectively filtering pixels within selected blocks of an image where an artifact may 10 be a problem. Further, the inventor realized that the sharpness of edges and, therefore, the quality of the decompressed image can be improved by selectively filtering pixels along an axis aligned generally parallel to the direction of an image edge. In the present invention, the direction of an image edge is detected and filtering is selectively applied to pixels arrayed along a filtering axis which aligned 15 relatively parallel to the direction of an image edge in a block.

In addition to the blocking effect, decompressed images may exhibit ringing artifacts that often appear as noisy lines in the vicinity of and approximately paralleling an image edge. In FIG. 1 a ringing artifact is illustrated by pixels of a third color 28 in the vicinity of the edge 22. A decompressed image may also 20 exhibit "staircase noise," a term which is descriptive of an appearance of an edge in the image. The staircase appearance is the result of enhancement of the blocking effect for blocks lying across an edge 22 in an image.

The steps of the post-processing technique of the present invention are illustrated in FIG. 2. To avoid over smoothing the image and conserve 25 computational resources, filtering is selectively applied to the pixels of selected blocks of the image. In a block selection step, the quantization parameter (QP) for each block is extracted from the data stream and compared to a predetermined quantization parameter threshold (QP_THRESHOLD) 102. The quantization parameter threshold is a selected maximum distance between quanta that produces a 30 visually acceptable transition across the block boundary. If the quantization

parameter is less than the threshold, the quantization error is not likely to create significant grid noise and an objectionable blocking artifact. If this is the case, the method selects the next block for examination 104 without filtering the current block. If the quantization parameter exceeds the quantization parameter

- 5 threshold, the block is designated for filtering.

If a block of pixels is to be filtered, the most dominant direction of an image edge in the block is determined 106. The edge direction is determined by comparing pixels in the vicinity of opposing boundaries of the block and located on projections of candidate filtering axes. Referring again to FIG. 1, the edge

- 10 detection investigation may be performed in the directions of four candidate axes; horizontal ($k=0$) 30, vertical ($k=2$) 32, and the 45° diagonals ($k=3$) 34 and ($k=1$) 36, to determine the dominant direction of the exemplary edge 22 in the block 12. The investigation could proceed along different, additional or intermediate candidate axes (for example, 22.5°) but the required additional
15 computation may not be justified by the improvement in the quality of the decompressed image.

Since a block loses much of its high frequency information in the compression process, inferring the direction of an image edge from pixels within the block can be difficult. Examining pixels that are members of neighboring

- 20 blocks and adjacent to the block boundaries 14, 16, 18, and 20 increases the area of the image subject to examination and improves the accuracy of the results. Corresponding pairs of pixels to be compared are located along projections parallel to each of the candidate axes 30, 32, 34, and 36 and in the vicinities of opposing block boundaries. For example, projections 38 and 40 parallel to
25 candidate axis 36 are used to identify pixels (1,0) 42 and (0,1) 44 and (3,0) 46 and (0,3) 48 in the vicinities of block boundaries 14 and 18 for comparison. Sub-sampling by a factor of two has been found to produce sufficient data points to identify the dominant edge direction and reduces the computational requirements. As a result, five pairs of pixels are investigated for the horizontal ($k=0$) 30 and
30 vertical ($k=2$) 32 axes and nine pairs of pixels are investigated for the diagonal

axes ($k=1$) 36 and ($k=3$) 34. Sub-sampling by a factor of two produces an exemplary data set as follows for an 8x8 block, where P_k^1 and P_k^2 are pixels of corresponding pairs on opposing block boundaries:

k	P_k^1	P_k^2
5	0 { (0,0), (1,0), . . . , (N+1,0) }	{ (0,N+1), (1,N+1), . . . , (N+1,N+1) }
	1 { (0,1), . . . , (0,N+1), . . . (N,N+1) }	{ (1,0), . . . , (N+1,0), . . . , (N+1,N) }
	2 { (0,0), (0,1), . . . , (0,N+1) }	{ (N+1,0), (N+1,1), . . . ,(N+1,N+1) }
	3 { (0,N), . . . , (0,0), . . . ,(N,0) }	{ (1,N+1), . . . , (N+1,N+1), . . . (N+1,1) }

- 10 The dominant direction of an image edge in a pixel block is identified by the candidate axis corresponding to the minimum sum of the mean absolute differences of the pixel values for each of the pluralities of corresponding pixels selected for investigation. In other words:

$$k_{\min} = \arg \text{MIN}_{\{0 \leq k \leq 3\}} |P_k^1 - P_k^2| / \text{DIM}(P_k^1)$$

- 15 where:

$|P_k^1 - P_k^2| / \text{DIM}(P_k^1)$ = the mean absolute difference of the corresponding pixels in the set of projection data in the direction of axis k

k_{\min} = the candidate axis returning the minimum argument

- 20 The difference between pixels at opposing boundaries on projections parallel to the edge 22 is assumed to be less than the differences between pixels sampled in the direction of candidate axes 30, 32, and 34 which lie on opposites the significant color or grayscale difference that characterizes an edge, such as edge 22. The candidate direction that produces the minimum sum is taken as the
 25 dominant direction of the edge 22 in the block 12 for the purpose of orienting the filtering axis for filtering the pixels of block 12.

Following determination of the dominant image edge direction, groups of contiguous pixels 49 (V_0, \dots, V_9) (filtering segments) (indicated by a bracket) bisected by the block boundary 14 and parallel to the identified edge direction or

filtering axis are identified for selective low pass filtering 108.

To avoid over smoothing the image, the two pixels of the filtering segment adjacent to the block boundary (V_4 and V_5) 50 and 52 are tested against two thresholds 110. First, if the absolute value of the difference between the pixels 5 (V_4 and V_5) 50 and 52 adjacent to the block boundary 14 is greater than twice the quantization parameter (QP), the pixels likely represent an image edge and filtering is not applied to avoid reducing the sharpness of the edge. On the other hand, filtering is not applied if the absolute value of the difference between pixels 50 and 52 adjacent to the block boundary 14 is less a predefined boundary 10 threshold (BD_THR) because the difference between the colors or grayscale of the pixels is insufficient to cause a visible blocking artifact. If the difference between pixels 50 and 52 of the filtering segment 48 adjacent to the block boundary is outside the upper and lower bounds established by these tests, then the next filtering segment is selected 112 without applying filtering to the current 15 segment.

If the difference between the pixels 50 and 52 adjacent to the boundary is within the upper and lower bounds, filtering of the segment is warranted and the continuity of the color or grayscale along the filtering segment is checked 114. A significant difference between adjacent pixels in a filtering segment, except at the 20 block boundary, is a probable indication of a detail within the block. The purpose of the discontinuity check 114 is to detect such a variation and limit filtering to a range of pixels within the segment so that filtering is not applied to the pixels representing the detail. Starting at V_4 50, the difference between the value of V_4 (V_i) and next contiguous pixel further removed from the boundary (V_3) 54 is 25 compared to a threshold (THRED). Likewise, the difference between pixel V_3 54 and pixel V_2 56 and each successive pair of pixels farther from the block boundary 14 will be compared to the threshold (THRED). If the difference for a pair of pixels exceeds the threshold (THRED), the pixel nearer the block boundary 14 is chosen as the lower bound to the filtering segment 49. Likewise, a 30 discontinuity check is performed, beginning at V_5 52, to establish an upper bound

to the segment. A filtering range comprising the portion of the filtering segment 49 including the pixels between the upper and lower bound produced by the discontinuity check ($V_{LB} \dots V_{UB}$) and including at least one pixel on each side of the boundary is filtered. The threshold may be a function of the quantization

5 parameter (QP) and the absolute value of the difference between the pixels adjacent to the boundary ($|V_4 - V_5|$). The threshold also may differ for blocks with different characteristics. For example, blocks might be characterized on the basis of the mean difference between pixels on opposing boundaries of the block as identified in the image edge direction identification step 108. For example, a
10 block might be typified as:

(a) simple, strong edge type if: $\text{Min_dif} < \text{THR_edge 1}$ and

$$\text{Max_dif} - \text{Min_dif} > \text{THR_edge 2}$$

(b) smooth if: $\text{Max_dif} < \text{THR_smooth}$

(c) complex if: the relationship of Min_dif and Max_dif is otherwise

15 where: Min_dif = the mean absolute difference in values
corresponding to k_{min}

Max_dif = the mean absolute difference in values
corresponding to k_{max}

THR_edge 1 = threshold edge 1

20 THR_edge 2 = threshold edge 2

THR_smooth = threshold of smooth transition

$$k_{min} = \arg \min_{\{0 \leq k \leq 3\}} |P_k^1 - P_k^2| / \text{DIM}(P_k^1)$$

$$k_{max} = \arg \max_{\{0 \leq k \leq 3\}} |P_k^1 - P_k^2| / \text{DIM}(P_k^1)$$

$|P_k^1 - P_k^2| / \text{DIM}(P_k^1)$ = the mean absolute difference of the corresponding pixels in the set of projection data in the direction of axis k

k_{\min} = the axis producing the minimum argument

5 k_{\max} = the axis producing the maximum argument

For example, the threshold (THRED) might be increased to facilitate more aggressive filtering of filtering segments in blocks classified as possessing a simple, strong edge. The threshold (THRED) can also be set to a level sufficient to avoid filtering details in the block while allowing filtering of the pixels of the

10 ringing artifact 28. Pixel repetition or symmetric extension may be used for filtering pixels near the segment boundary (V_{LB}, \dots, V_{UB}).

Following determination of the filtering range, the pixels of the filtering range ($V_{LB} \dots V_{UB}$) are filtered 116 and the method selects the filtering segment for processing 112. Filtering is necessary only along the left vertical boundary 14 and 15 the lower horizontal boundary 20 of the block 12 because filtering is usually applied in the direction of the raster scan and the remaining block boundaries 16 and 18 are subject to filtering when the neighboring blocks are filtered. Any low pass filter may be used for filtering the filtering range. A seven tap filter that has been found to produce acceptable image quality can be implemented as 20 described in TABLE A.

In addition, a short filter mode may also be provided for in the method of the present invention. A large variation in intensity for the pixels of the filtering segment 49 indicates that the segment is in an area of the image 10 having a high level of detail texture. If this is the case, the short filtering mode can be selected 25 and the values of the two pixels 50 and 52 adjacent to the block boundary 14 replaced by their average value to reduce the blocking effect.

The method of the present invention is also useful for post-processing the image of an interlaced video field. Since the two fields often undergo different operations during compression (for example, motion estimation or compensation 30 and DCT coding), it is advantageous to apply post-processing separately to the

images represented by the individual fields. Applying post-processing separately to the fields avoids the complication of block classification and confusing an intensity change between fields (resulting from either field capture or compression) as an image edge. Identifying an intensity change between fields

- 5 as an image edge is a particular problem at the boundaries of moving objects. Slightly better performance may also be possible if adaptive separation is based on the mode of compression of each macro-block (field or frame motion compensation).

All the references cited herein are incorporated by reference.

- 10 The terms and expressions that have been employed in the foregoing specification are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding equivalents of the features shown and described or portions thereof, it being recognized that the scope of the invention is defined and limited only by the claims that follow.

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TABLE A
Implementation of a seven tap filter

```

/* LPF7: (1 2 3 4 3 2 1)/16 */

5      /* v[i]: segment of input data to be filtered
           u[i]: segment of output data
           LB, HB: lower bound and upper bound of the smaller
           segment that is actually filtered */
for(l=-3, psum=4; l<=3;l++)
10    {
        if(l+LB>=0) psum+=v[l+LB];
        else psum+=v[0];
    }
    for (l=LB; l<=HB; l++)
15    {
        switch (l)
        {
            case 1:
                u[1] = (((psum + v[1]) << 1)+(v[2] - v[4])) >> 4;
                psum+=v[5]-v[0];
                break;
            case 2:
                u[1] = (((psum + v[1]) << 1)+(v[3]+v[1]) - (v[5] + v[0])) >> 4;
                psum+=v[6]-v[0];
                break;
            case 3:
                u[1] = (((psum + v[1]) << 1)+(v[4]+v[2]) - (v[6] + v[0])) >> 4;
                psum+=v[7]-v[0];
                break;
        }
    }

```

case 4:
5 $u[i] = (((psum + v[i]) << 1) + (v[5] + v[3]) - (v[7] + v[1])) >> 4;$
 $psum += v[8] - v[1];$
 break;
case 5:
10 $u[i] = (((psum + v[i]) << 1) + (v[6] + v[4]) - (v[8] + v[2])) >> 4;$
 $psum += v[9] - v[2];$
 break;
case 6:
15 $u[i] = (((psum + v[i]) << 1) + (v[7] + v[5]) - (v[9] + v[3])) >> 4;$
 $psum += v[9] - v[3];$
 break;
case 7:
20 $u[i] = (((psum + v[i]) << 1) + (v[8] + v[6]) - (v[9] + v[4])) >> 4;$
 $psum += v[9] - v[4];$
 break;
case 8:
 $u[i] = (((psum + v[i]) << 1) + (v[7] - v[5])) >> 4;$
 break;
20 }
 }